This invention also reduces the impact of packet loss on video data quality. For a fixed packet drop rate, the video data quality is improved by reducing the number of high priority packets being dropped.

Additionally, the invention intelligently selects packets to deliver so that a higher video data quality may be obtained when not all the packets can be transmitted on time.

By selecting a threshold h appropriately, in most cases, the invention can perform within 1-3% of the optimum result determined by the channel conditions and operation is significantly improved as the result of utilizing packet selection.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments of this invention will be described in detail, with reference to the following figures, wherein:

Fig. 1 illustrates a video data transmission system according to a preferred embodiment of the invention;

Fig. 2 illustrates a two state Markovian channel model;

Fig. 3 illustrates a representation of a video data stream, where each column represents one frame while each row represents one layer;

Fig. 4 illustrates an exemplary method of determining whether to transmit a packet by estimating the value of success probability as used in the first exemplary embodiment;

Fig. 5 shows exemplary constant bit rate video data used to illustrate the application of the exemplary embodiments;

Fig. 6 shows exemplary variable bit rate video data used to illustrate the application of the exemplary embodiments;

~~Figs. 7(a)-7(e) show simulation results with the quality index plotted as a function of system load for different channel condition transition probability p_{GG} and for thresholds h = 0.1, 0.5, 0.7, 0.9 and 0.99, respectively;~~

Fig. <u>7</u> ~~8~~ illustrates an exemplary method of determining whether to transmit a packet by estimating the value of success probability including operation steps for backing up the transmission as used in the second exemplary embodiment;

~~Figs. 9(a)-9(e) show simulation results using the parameters used in the simulation of Fig. 7(a)-7(e) for the method illustrated in Fig. 8;~~

Amend page 5 as follows:

~~Figs 10(a)-10(c) show simulation results using a constant bit rate video data file with the threshold h being set at 0.7, 0.9, and 0.99, respectively, for the method illustrated in Fig. 4; and~~

~~Figs 11(a)-11(c) show simulation results using the parameters used in the simulation of Figs. 10(a)-10(c) for the method illustrated in Fig. 8.~~

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With a same amount of data, variable bit rate (VBR) encoding can generally achieve better video data quality than constant bit rate (CBR) encoding. However, efficient transmission of VBR video data has always been among the most challenging problems to network designers, largely because of the video data's high bandwidth demand, the quality of signal (QoS) requirements and the significant rate of variability.

In the present invention, video data smoothing is used as an effective way to reduce the variability of the bandwidth requirement for transmitting the video data, which can potentially simplify other operations such as resource allocation and improve network utilization.

Video data smoothing preloads part of the video data to a smoothing buffer at the client before play-out. After play-out has started, the rest of the video data may be transmitted in a less bursty fashion without compromising the quality of the video data. For given video data, video data smoothing generates the transmission schedule, which includes the rates at which the video data will be delivered during play-out, based on buffer size, available bandwidth and allowed play-out delay. A valid transmission schedule must guarantee that, given the bandwidth it requires, the smoothing buffer will not overflow or underflow during the entire play-out of the video data. Depending on the user's requirements, the smoothing algorithm may also need to optimize certain characteristics of the transmission schedule, such as peak rate, number of rate changes, etc.

When video data needs to be delivered over a wireless network, it becomes even more important to perform smoothing. Wireless channels typically have smaller capacity than wired links, which limits the gain provided from multiplexing. By reducing the burstiness of the bandwidth requirement through smoothing, more streams may be

Amend page 19 as follows:

packet 2000 bits or lower depending on the actual transmission rate. Equation (1) and (2) were used to estimate the value of success probability $SP_{f,l}$ with $R = 28$.

The performance of any method or system for packet selection largely relies upon the threshold h used. Therefore, the relationship of the performance and the chosen threshold h will now be explained under various network conditions. Specifically, the value of p_{GG} was varied from 0.01 to 0.91 in steps of 0.1 and the case with $p_{GG} = 0.99$ was also considered. Also, for a fixed p_{GG}, the value of p_{BB} was adjusted to obtain different network loads.

For each pair of p_{GG} and p_{BB}, the transmission performance was investigated by measuring the output video data's *QI* using five different thresholds $h = 0.1$ ~~(Fig. 7(a))~~, 0.5 ~~(Fig. 7(b))~~, 0.7 ~~(Fig. 7(c))~~, 0.9 ~~(Fig. 7(d))~~ and 0.99 ~~(Fig. 7(e)). Figs. 7(a)-7(e) show the results with the *QI* plotted as a function of system load for different~~ $\cancel{p_{GG}}$ ~~and thresholds~~ $\cancel{h}$. ~~Each graph corresponds to a fixed threshold~~ $\cancel{h}$, ~~and for each curve in a graph,~~ $\cancel{p_{GG}}$ ~~is fixed.~~

Comparing the data ~~graphs in Figs. 7(a)-7(e)~~, the *QI*, which indicates the transmission performance, first increases as the threshold h increases, then as the threshold h approaches one, it starts to decrease. This is an expected result because, with a small threshold value h, the packet selection system tends to transmit more packets for each frame before advancing to the next one. This means by the time the system is ready to transmit later frames, it may not have enough time for even their high priority components. Therefore, some high priority packets may not be delivered because the system spent too much time on the earlier lower priority packets. Therefore, the performance of the system may be improved.

As the threshold value h increases, less low priority packets are transmitted which leaves more room for higher priority packets behind them, thus the performance improves and the *QI* increases. However, if threshold h continues to increase, the system approaches the other extreme state. It becomes more and more likely that only the highest priority layer will be sent, even if some less important packets could have been delivered without affecting the outcome of the future frames. As a result, the

Amend page 20 as follows:

performance degrades with the increasing threshold value h. From the data ~~In Figs. 7(a)-7(e)~~, the performance tops at around $h = 0.7$.

The exact threshold value h at which packet selection provides optimum transmission performance depends upon channel conditions and may change for different video data streams. As packet selection has been described so far, it is possible that the packet selection system decides to skip the rest of a frame and start sending layer 0 of the next frame, but no packet of this new frame has yet arrived at the base-station. While waiting for these packets, the bandwidth, which is otherwise wasted, could have been used to deliver skipped packets. Simulation results indicate that the problem becomes more and more likely to occur as the threshold h increases. Thus, it is also responsible for ~~the~~ rapid degradation of performance ~~seen in Figs. 7(a)-7(e)~~ as the threshold h approaches one.

One way of improving the efficiency of bandwidth usage in this situation is to go back and transmit packets that were previously skipped. This operation is referred to as "backing up" the transmission. Here, it is assumed that packets skipped are kept in the base-station buffer until after their play-out time or are replaced by newly arrived packets. As soon as the awaited high priority packet arrives, the original packet selection steps are resumed and the new packet is delivered. Transmission may be backed up whenever similar situations occur.

If backing up is employed to further improve transmission, the method illustrated in Fig. 4 is altered to include additional steps as shown in Figure 7 ~~8~~. In this second exemplary embodiment shown in Fig. 7 ~~8~~, the method begins in step 800 and control proceeds to step 810. In step 810, it is determined whether the frame k will be played before the end of the next mini slot. If frame k will not be played before the end of the next mini slot, control proceeds to step 812. Otherwise, control proceeds to step ~~900~~ 880. In step ~~900~~ 880, transmission of layer 0 of the next frame that will not be played before the end of the next mini slot is performed and control proceeds to step ~~910~~ 885.

In step 812, it is determined whether layer 0 of frame $k + 1$ or layer i of frame k is available for transmission. If so, control proceeds to step 815. Otherwise control proceeds to step 850, explained in detail below.

Amend page 22 as follows:

~~Figures 9(a)-9(e) show the simulation~~ Simulation results of the second exemplary embodiment of the invention, with the backup procedure incorporated, were obtained using the same parameters used earlier, and ~~in the simulation of Figs. 7(a)-7(e)~~. ~~Fig. 9(a) illustrates the simulation results~~ for $h = 0.1$, ~~Fig. 9(b) corresponds to~~ $h = 0.5$, ~~Fig. 9(c) corresponds to~~ $h = 0.7$, ~~Fig. 9(d) corresponds to~~ $h = 0.9$ and ~~Fig. 9(e) corresponds to~~ $h = 0.99$.

The backup procedure always chooses, among all the skipped packets, the one with highest priority and lowest index to deliver. ~~Figs. 7(a)-7(e)~~ The data show that, using a small threshold value h, the performance of the second embodiment is not much altered from the performance of the first embodiment. However, for higher thresholds h, performance improves significantly. For example, for some combinations of p_{GG} and p_{BB}, the *QI* obtained with $h = 0.9$ ~~(Fig. 9(d))~~ exceeds that when $h = 0.7$ ~~(Fig. 9(c))~~.

Moreover, with such an improvement, the performance also becomes more stable. In particular, performance is within 1-3% of the optimum result over a relatively large load range, with $h = 0.7$ ~~(Fig. 9(c))~~ and $h = 0.9$ ~~(Fig. 9(d))~~. This large range makes it easier to select an appropriate threshold value h for different video data streams.

Comparing $h = 0.1$ ~~(Fig. 9(a))~~ data with $h = 0.5$-0.99 data ~~(Figs. 9(b)-9(e))~~, it should be clear that use of a very small threshold h results in consistently poor performance. For any fixed p_{GG}, the corresponding ~~curve~~ data for $h = 0.1$ ~~in Fig. 9(a)~~ is always the lowest among the data ~~all five graphs~~. This substantiates a conclusion that systems that do not implement packet selection as used in the present invention (equivalent to the case of $h = 0$), such as conventional transmission systems, do not perform well.

The actual amount of improvement from implementing the packet selection provided by the exemplary embodiments depends upon the channel conditions and the selected threshold value h. Moreover, improvement is also generally higher for higher p_{GG} and higher network loads.

Additionally, ~~Figs. 7(a)-7(e)~~ the data indicate that~~, for some curves,~~ as system load increases, the *QI* sometimes increases with the load, while sometimes decreases with it, especially at $h = 0.9$ ~~(Fig. 7(d))~~ and $h = 0.99$ ~~(Fig. 7(e))~~. This correlation, or inverse correlation, phenomenon is even more apparent in ~~Figures 10(a)-10(c) which graph~~ another simulation that used a computer generated CBR video data file that included 4000 equal-sized frames and the size of a frame is 2000 bits. In each frame, 1000 bits

Amend page 22 as follows:

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Amend page 23 as follows:

were of the highest priority, and for the rest of 1000 bits, half were of priority 1 and the other half were priority 2. The simulation assumed a play-out period of 6 mini-slots. One frame was sent from the server, hence one was received at the base-station, every 6 mini-slots. The size of the wireless packet was 500 bits and that of a regular packet was equal to the frame size. The initial buffer occupancy at the client was 6000 which was exactly the total of the first three frames. ~~The~~ A simulation ~~of Figs. 10(a)-10(c)~~ was performed to investigate how QI changes with load by fixing the value of p_{GG} and changing p_{BB} for different thresholds , h [.]

~~Figs. 10(a)-10(c) show the results of this simulation with the threshold h~~ being set at 0.7, 0.9, and 0.99, respectfully. ~~It is clearly shown in Figs 10(a)-10(c)~~ The data shows that most of the curves drop suddenly once or twice as the load increases from 0.6 to 2. To provide more specific results, Table 1 lists the total number of packets transmitted in each layer when $p_{GG} = 0.71$ for the three thresholds $h = 0.7$, $h = 0.9$ and $h = 0.99$. This data indicates that the reason why the QI curves drop suddenly at some points, when p_{BB} exceeds certain value, is that almost an entire layer is lost.

The exact value of this critical point for p_{BB} depends on p_{GG} and threshold h. For instance, when threshold h equals 0.7, starting from $p_{BB} = 0.71$, almost the entire layer 2 is dropped. When $h = 0.9$, most of the layer 2 packets are dropped starting from $p_{BB} = 0.41$; and from $p_{BB} = 0.71$, all layer 1 packets are also dropped. While for $h = 0.99$, the two drops take place even earlier at $p_{BB} = 0.11$ and $p_{BB} = 0.31$ respectively. Right after each drop, the number of packets transmitted in each layer changes very little as p_{BB} increases. However, the load increases with p_{BB}, which means the best quality one can achieve from the system actually worsens rather than improves as p_{BB} increase. Therefore, the relative performance of the system becomes better, the QI increases and the curve goes up with the load.

An explanation for these sudden drops is now provided. In the exemplary embodiments, as explained above, $P_{X_l,R}$ is calculated to determine which packet to deliver at the end of each mini-slot. For a long CBR video data stream, ~~such as that used in the simulation associated with Figs. 10(a)-10(c),~~ calculation of:

Amend page 24 as follows:

$$X_1 = \left\lceil \frac{(layer\ 0\ size = layer1\ size) * (number\ of\ frames\ left) * R}{(wireless\ packet\ size) * (number\ of\ \text{mini-slots}\ left)} \right\rceil$$

is performed to decide whether to select a layer 2 packet, and calculation of:

$$X_0 = \left\lceil \frac{(layer\ 0\ size = layer1\ size) * (number\ of\ frames\ left) * R}{(wireless\ packet\ size) * (number\ of\ \text{mini-slots}\ left)} \right\rceil$$

is performed to decide whether to select a layer 1 packet. For a CBR video data stream, the only factor that may vary in the above two formulas is the ratio between the number of remaining frames and the number of remaining mini-slots.

Since only one frame is sent from the server in every time slot, with a play-out delay of just 3 time slots, a packet does not arrive at the base station until a few time slots before its play-out time. Therefore, the ratio, X_l, does not change much during the entire play-out. As a result, the estimated success probability $P_{X_l,R}$ also does not change appreciably during the entire play-out. Therefore, with a fixed threshold h, it is likely that the minimum success probability of a layer remains either above or below the threshold h during the entire play-out. In the latter case, an entire layer is dropped. Since layer 2 packets need to consider one more layer than those of layer 1, their success probabilities are more likely to fall below the threshold h.

Therefore, the cause of these sudden drops is that, again, the system is waiting for higher priority packets which have not arrived at base-station, while it could be sending some skipped lower priority packets. As described previously, this problem is remedied by the second exemplary embodiment shown in Fig. 7 ~~8~~.

The simulation results of the second exemplary embodiment, using the same parameters as used in the previous simulation ~~of Figs. 10(a)-10(c), are shown in Figs 11(a)-11(c). Although~~ show that although the curves still drop and then increase at about the same points ~~as those in Figs. 10(a)-10(c)~~, the drops are to a much less significant degree. The use of the backup procedure results in improvements that are especially significant for large threshold values h. When using the backup procedure in the second exemplary embodiment of the invention, the performance is predominantly within 5% of the optimum result even for $h = 0.9$ and $h = 0.99$.

Amend page 25 as follows:

~~The degree of similarity between Figs. 11(b) and 11(c) is also worth noting. This similarity occurred because~~ The data shows that the majority of the low priority packets have success probabilities that are less than both thresholds h. Therefore, the majority of the low priority packets are transmitted through the backup procedure of steps 850-880 in the method illustrated in Fig. ~~8~~ 7. As a result, the exact value of the threshold h is less significant than in the first illustrative embodiment (Fig. 4), which does not use a backup procedure.

~~The 'bumpy' results in Figs. 7(a)-7(e) are due to a similar reason. However, the~~ The success probability $SP_{f,l}$ does vary over a relatively large range during play-out, and the dropping effect is not as dramatic and more complex because the video data used in that simulation includes different frame sizes. By using the second illustrative embodiment of the invention, with the incorporated backup procedure, the sudden drops in performance almost completely disappear ~~as shown by a comparison between Figs. 7(a)-7(e) and Figs. 9(a)-9(e)~~.

The wireless channels used in the simulations can be fully characterized by the value of p_{GG} and p_{BB}. A comparison of the performance of the exemplary embodiments of the invention under different system loads is now provided. This comparison explains how the performance is affected by p_{GG} and p_{BB}, as well as how to select the threshold h to obtain better results.

Using the first exemplary embodiment of the invention, ~~Figs. 7(a)-7(e) show~~ data shows that, under the same load, performance is generally better for small p_{GG}, i.e., when both good periods and bad periods are short, than for larger p_{GG}, i.e., when the system usually remains in the good state for a long time, but once in the bad state, does not return to the good state for a significant period of time. However, using the second exemplary embodiment, with a backup procedure incorporated, the difference between various combinations of p_{GG} and p_{BB} becomes almost negligible. This is especially true for $h = 0.7$ and $h = 0.9$ ~~, as shown in Figs. 9(a)-9(e)~~. In other words, with a threshold h between 0.7 and 0.9, the transmission is performed close to optimum under most of the channel conditions. The only exception is when p_{GG} is very high, e.g., above 0.99. ~~Figs. 9(a)-~~

Amend page 26 as follows:

~~9(e).~~ The data show that, at $p_{GG} = 0.99$, the performing packet selection provides almost no performance improvement unless the threshold h is also set to be very high. In actual implementation, setting the threshold h between 0.7 and 0.9 will obtain near optimum performance in most cases. An exception is when p_{GG} is close to 1, in which case the threshold h also needs to be set to be very close to 1.

Simulation results indicate that by selecting the threshold h appropriately, the first exemplary embodiment of the invention achieves within 5% of the optimum result under most channel conditions. Moreover, simulation results also indicate that implementing the second exemplary embodiment of the invention, which includes a backup procedure that uses an otherwise idle network to deliver skipped packets, further improves performance to within 1-3% of optimum transmission capability. Additionally, using the second exemplary embodiment of the invention provides a more stable system that is capable of using a large range of threshold values h under different network conditions. Therefore, the second exemplary embodiment of the invention allows more opportunity to choose thresholds h for different video data streams.

While this invention has been described in conjunction with the specific embodiments outlines above, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention, as set forth above, are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention.

For example, the present invention may be employed with various coding schemes. Some coding schemes use interframe techniques. For instance, in MPEG, a B frame may need the I or P frame behind it in order to be decoded. Therefore, efficiently transmitting the B frame by itself does not improve video data quality if the corresponding I or P frames are missing. Therefore, the order in which compressed pictures are found in the video data stream may be different from the order in which they are played.

Initially, this might suggest that the present invention may not be utilized in such interframe coding schemes. However, the benefits of the present invention may be used in such coding schemes with minor modifications to the system and method.